XXI. *On the structure of the crystalline lens in fishes and quadrupeds, as ascertained by its action on polarised light.* *By* David Brewster, *LL.D. F. R. S. Lond. and Edin. In a Letter addressed to the Right Hon. Sir Joseph Banks, Bart. G. C. B. P. R. S.*

Read June 20, 1816.

Dear Sir,

There is, perhaps, no subject in natural history which has excited so much attention, as the structure and functions of the eyes of animals; and there is certainly none which has so ill repaid the anxiety and labour with which it has been investigated. The physiologist was naturally led to study the mechanism of an organ through which man receives the noblest of all his enjoyments; and the natural philosopher, considering it as the work of infinite intelligence, ardently anticipated the improvement of optical instruments from the imitation of this perfect model. It is discouraging however, to estimate the real amount of the labours of the one, and to perceive how little advantage has been derived from them by the other. The most prominent functions of the eye are still very imperfectly understood, and the improvement of the telescope has been retarded, rather than advanced, by the pursuit of a false analogy. I have, therefore, some satisfaction in being able to throw additional light upon a subject of such difficult investigation, and so generally interesting both from its optical and physiological relations.

Having found that the doubly refracting structure could be communicated to glass and other bodies, by giving them a variable density either through the agency of heat or mechanical pressure, I was led to conclude, that the same structure would be found in the crystalline lens of fishes and other animals, which was known, by direct experiment, to increase in density towards the centre. I had formerly examined the action of the crystalline upon polarised light, without obtaining any new result; but I now placed such reliance on the truth of the general principle, that I resumed the subject with the utmost confidence of success.

Upon exposing to a polarised ray the crystalline lens of a large cod, included in its capsule, I could not perceive, as happened in my early experiments, any very distinct indications of a peculiar action. I plunged it, however, in Canada balsam contained in a hollow parallelopiped of glass, and was surprised to observe a regular optical figure varying its shape during the revolution of the crystalline.

I now turned the spherical crystalline, till the diameter which corresponded to the axis of the eye, or the line joining the poles to which the fibres converge, was parallel to the polarised ray, and I observed the appearance shown in Fig. 1. (Pl. XII.) consisting of twelve luminous sectors, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, separated from each other by a black cross, and by two dark concentric circles. The interior sectors, 1, 2, 7, 8, were small and exhibited a white tint of the first order, increasing in brilliancy towards the centre. The middle sectors 3, 4, 9, 10, which are very large, are separated from the interior ones, by a broad dark circle, and display a white tint of the same intensity. The outer sectors

5, 6, 11, 12, are extremely faint, and are seen with considerable difficulty in this position of the lens.

If the crystalline is now turned round, so that its axis, which corresponds to the axis of vision, may always be parallel to the polarised ray, the same appearances will be seen without the slightest variation. But if this axis is inclined to the polarised ray in the direction 1, 2, the sectors 1, 2, will diminish, and 7, 8, will increase in size, and an additional white spot will appear at the centre as in Fig. 2, till by increasing the inclination, the sectors 1, 2, and the white spot will completely disappear, leaving the sectors 7, 8, much enlarged and of a bluish white tint. If the inclination is in the direction 7, 8, the sectors 1, 2, will increase, and 7, 8, will diminish in the same manner.

By transmitting the polarised light through other two faces of the glass parallelopiped, so as to traverse the crystalline in a line perpendicular to its axis, the optical figure presented new appearances. When the axis of the lens was either parallel or perpendicular to the plane of primitive polarisation, which happened four times in the course of a revolution, it exhibited the form shown in Fig. 3. The tints 1, 2, 7, 8, were now reduced to a pale blue of the first order, and the black cross was very ill defined at the centre. The middle sectors 3, 4, 9, 10, were a little reduced in size, while the exterior ones 5, 6, 11, 12, had experienced a very sensible augmentation. At intermediate positions of the crystalline, when its axis was inclined 45°, 135°, 225°, and 315° to the plane of primitive polarisation, the optical figure assumed the appearance shown in Fig. 4, where the two sectors 7, 8, are greatly enlarged, and the other two 1, 2, have wholly, or almost wholly, disappeared.

I now removed the capsule of the lens, so as to let out the semifluid matter which it enclosed, and having rubbed off the very soft exterior coat, I immersed the diminished sphere in Canada balsam, but I could never observe the exterior sectors, 5, 6, 11, 12, all the other appearances being exhibited as before. I next removed the middle coats of the crystalline, and replacing the nucleus, which was now reduced to one-eighth of an inch in diameter, in the glass parallelopiped, I observed the central sectors 1, 2, 7, 8, without any of the middle or exterior ones. By pressing the nucleus between two plates of glass, or by allowing it to indurate gradually, the depolarised tints ascended in the scale of colours, as in the case of animal jellies.

If we now take a plate of sulphate of lime which polarises a blue of the second order, and combine it with the crystalline lens, so that its axis may be parallel to the line 6, 10, 2, 1, 9, 5, the white tints 9, 10, will ascend to a green of the second order, while those at 1, 2, 5, 6, will descend to an orange red of the first order. In like manner, if the axis of the plate of sulphate of lime is parallel to the line 11, 3, 7, 8, 4, 12, the tints 3, 4, will become green, and 7, 8, 11, 12, an orange red.

Hence, it follows, *that the nucleus* 1, 2, 7, 8, *and the exterior coat*, 5, 6, 11, 12, *have the same structure as one class of doubly refracting crystals*, while the middle coats 3, 4, 9, 10, have the structure of the other class.

In order to compare these different structures with those of glass crystallized by heat and by pressure,* I took a polished sphere of crown glass, and, having brought it to a red heat, I cooled it by rolling it quickly in every direction over a smooth surface. When it was immersed in Canada balsam,

* See Phil. Trans. 1816, p. 46, 156.

and exposed to polarised light, it had the appearance shown in Fig. 5, in whatever position it was held, the highest tint being an orange yellow of the first order. By examining these sectors with sulphate of lime, I found that the glass had the same structure as the middle coats of the crystalline. In like manner, it appeared that the sectors, exhibited by pressing a convex lens upon a flat piece of glass, were produced by a structure the same as that of the central nucleus of the crystalline. The structure of the crystalline lens, in short, is similar to that of a plate of glass that gives the unusual fringes* bent into a circular shape. Hence it follows, *that the central nucleus and the external coat are in a state of dilatation, while the intermediate coats are in a state of contraction, and that these opposite states are not dependent upon each other as in crystallized glass.*

The phenomena which have now been described are visible also in the crystalline of the *haddock.* They appear likewise in that of *sheep* and *oxen,* but there is here only one series of luminous sectors corresponding with the intermediate set in the crystalline of fishes. The human crystalline will no doubt display similar properties, but in an inferior degree.

The *cornea* both of fishes and quadrupeds, and also the human cornea, have an analogous structure; in which the optical axes of all the particles are directed to its centre. Its structure is the same as that of the internal nucleus, and it produces an effect upon polarised light similar to what is shown in Fig. 6.

The *sclerotic coat* of fishes has the property of depolarising light in separate spots like the diamond, or a mass of crushed

† See Phil. Trans. 1816, p. 65, 66.

isinglass; but it derives this property from a bluish white membrane which covers the outside of it, for when this is removed, it loses the doubly refracting structure. If the sclerotic coat is boiled, it is capable of receiving the structure of doubly refracting crystals by mechanical compression and dilatation. In its natural state, it possesses the same property, but in an inferior degree. The cornea is also capable of having its doubly refracting force increased by compression or dilatation.

From these experiments the following conclusions may be deduced.

I. All the parts of the crystalline lens of fishes corresponding to the two dark concentric circles, exercise no action upon polarised light. The outward spherical shell which acts upon light like one class of doubly refracting crystals, and also the solid nucleus which exercises a similar action, are in a state of mechanical dilatation, while the middle spherical shell which acts upon light like the other class of crystals, is in a state of mechanical contraction.*

II. The structure of the crystalline lens in fishes is not symmetrical, as has hitherto been supposed, consisting merely of a number of coats of different densities; but it has a distinct relation to that diameter of the sphere which is the axis of vision.

III. The variations of density which produce the doubly refracting structure, are not related to the centre of the crys-

* When the crystalline lens is examined by common light, there is an obvious appearance of a rapid change of density at the line which separates the middle and the exterior sectors. This is probably the boundary of the fluid coat adjacent to the capsule.

Fig. 1.

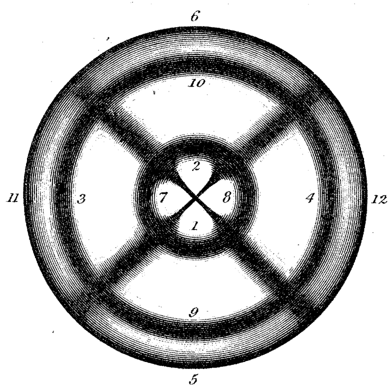


Fig. 3.

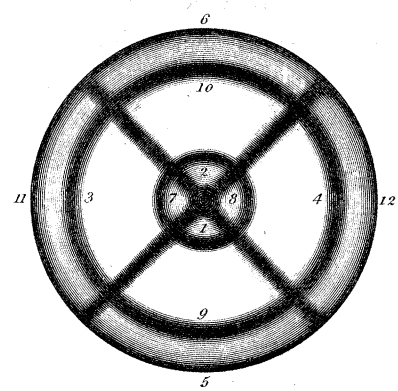


Fig. 4.

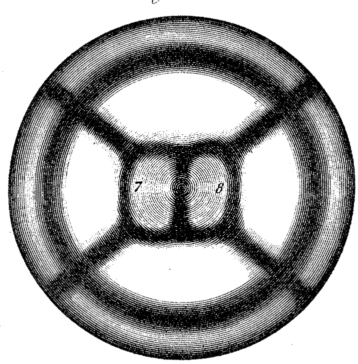


Fig. 2.

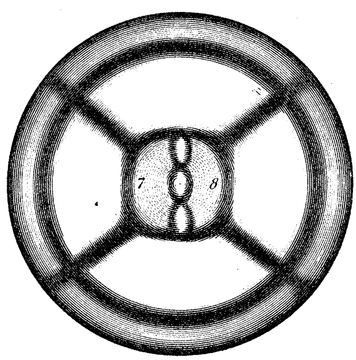


Fig. 5.

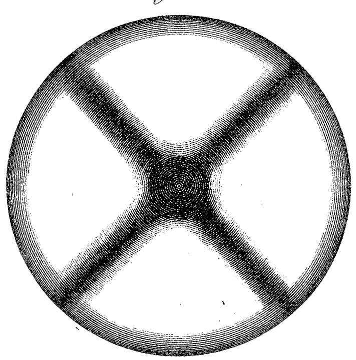
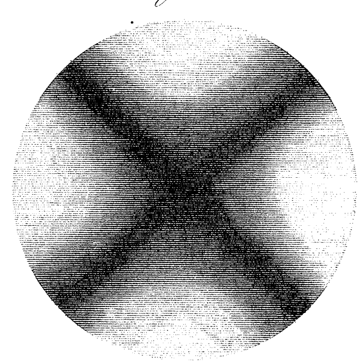


Fig. 6.



talline, but to the diameter which forms the axis of vision. For if the variation of density were related to the centre, the sphere would have a symmetrical structure, and like the glass ball already mentioned, would exhibit the same figure in every position.

IV. It is highly probable, that this peculiar structure of the crystalline is necessary for correcting the spherical aberration.

I have the honour to be, &c.

D. BREWSTER.

To the Right Hon. Sir Joseph Banks, Bart. G. C. B. P. R. S.

Edinburgh, May 20, 1816.